Greenhouse theory and
climate change

THE GREENHOUSE THEORY AND CLIMATE CHANGE

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ISSUE DEFINITION

Over the last quarter-century, scientists have demonstrated that the amount of carbon dioxide (CO_2) is increasing in the atmosphere. A rise of about 4% in CO_2 concentration during the 1970s alone and of 8% over the last 25 years has been measured; an increase of some 20-30% since the beginning of the Industrial Revolution is inferred. What this environmental shift may mean for the planet and mankind is a matter of controversy.

The greenhouse theory holds that adding large quantities of carbon dioxide, and just as importantly, other trace gases, to the atmosphere will warm the earth. Some climatologists and many environmental groups believe that the higher concentrations of these gases will induce a global warming sufficient to cause extensive change in climatic patterns. On the other hand, many scientists are still far from convinced by warming theories. Global warming claims are based solely on theoretical models of the atmosphere, as of yet there is no solid scientific evidence to support model projections. The models are complex, and even scientists who are strong advocates of greenhouse theories admit that important scientific data are lacking and that analyses are oversimplified. In December 1991, Dr. John Houghton, chief editor of the U.N.-sponsored Intergovernmental Panel on Climate Change (IPCC) Report, which formed the basis for the global warming portion of the UNCED Earth Summit, announced a much reduced prediction of future climate warming, based on new studies.

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* The original version of this Current Issue Review was published in September 1979; the paper has been regularly updated since that time.

BACKGROUND AND ANALYSIS

A. The Relationship between Atmospheric CO_2 and Climate

The earth receives radiant energy from the sun but it must reradiate that energy back into space or our world would become progressively hotter. Solar energy arrives at the earth's surface at wavelengths lying predominantly within the visible part of the electromagnetic spectrum. The earth re-radiates energy, however, at longer wavelengths which concentrate in the far infrared or "heat" end of that spectrum. The energy of these longer wavelengths is more readily absorbed by naturally occurring CO_2 and water vapour in addition to other infrared-absorbing gases such as nitrous oxide, methane, chlorofluorocarbons and ozone. This absorption occurs primarily in the troposphere, the region from the earth's surface up to an altitude of 10 to 15 km.

When these molecules absorb energy, they cause general atmospheric warming, a phenomenon commonly called the "greenhouse effect." These gases thus act like a "thermal blanket" around the earth, and as their atmospheric concentration increases, together with the absorption of energy in the infrared, incoming radiation temporarily exceeds outgoing radiation. The temperature of the atmosphere rises and a new radiation balance is established.

Early estimates of the increase in the mean global temperature of the lower atmosphere that could result from a doubling of the present CO_2 concentration lay between 1.5° and 4.5°C. The more recent and more complex model of Dr. J. Mitchell and co-workers at the United Kingdom Meteorological Office takes into account previously missing feedback phenomena and predicts maximum global mean annual surface air warming in the range of 1.9 to 2.5°C.

B. Sources of Carbon Dioxide (Fossil Fuels and Deforestation)

Carbon dioxide is the vehicle which transports carbon through the carbon cycle. It is removed from the air by plants during photosynthesis to make solid organic compounds, and when these compounds are respired, CO_2 is again released to the atmosphere. Carbon dioxide dissolves in the oceans as bicarbonate and can be converted to the solid, calcium carbonate, by shellfish. In the very long-term, CO_2 can be converted to fossil fuels. Thus, carbon dioxide is part

of the cycle of carbon circulation (a biogeochemical cycle) which consists of both living and nonliving components.

Over the last half-billion years of our planet's more than 4.5-billion-year history, a small percentage of the carbon circulating through the earth's surface environment has been diverted and stored in sedimentary rocks as fossil fuels. In mankind's recent history there is believed to have been an approximate balance in the exchange of carbon between the atmosphere and the oceans. Industrial activity, however, is returning to the atmosphere within a century or two a portion of the carbon that nature accumulated in fossil fuels over many millions of years.

Fossil fuel combustion has released an estimated 160 billion tonnes of carbon to the atmosphere since 1900, with the present contribution calculated to be approximately 5 billion tonnes annually. Future levels of emissions are conjectural, depending upon the assumptions one makes regarding population growth, technological change, the global economy, energy conservation, fuel costs and the evolution in the mix of energy sources to satisfy energy requirements.

Terrestrial biota and soils contain roughly three times as much carbon as the atmosphere; accordingly, their alteration can add CO_2 to, or subtract it from, the atmosphere. Intensive agriculture and various development activities may bare the soil surface and lead to erosion and loss of organic carbon. Forest harvesting without provision for natural regeneration or reforestation may result in a net loss of carbon if the wood is burnt. If the area is reforested and the wood used for construction purposes, however, then there is a net capture of carbon dioxide.

C. Sinks of Carbon Dioxide (Vegetation, Oceans and Waste)

Measurements suggest that only about half of the total amount of anthropogenic CO_2 produced over the last century has actually stayed in the atmosphere; CO_2 must be absorbed or stored somewhere or the atmospheric concentration would be greater than observed.

Introducing new crops into previously unsuitable climatic zones and fertilizing plants to stimulate growth may well be countering much of the carbon loss due to deforestation and land disturbance. In addition, higher concentrations of carbon dioxide have been found to stimulate

both the rate and extent of plant growth in the vast majority of species tested. The possible benefits of increased carbon dioxide concentrations on world agriculture is now just beginning to be appraised.

In North America, the uptake of CO_2 from the atmosphere by growing forests is greatly improved over what it was 100 years ago. Today, lumber companies are obliged to replant harvested forests. Also, in Canada and the United States, marginal and abandoned farmlands are reverting to forested areas either naturally or under the auspices of a variety of federal, state or provincial reforestation programs. Forest cover in the United States has expanded from 464 million acres in the 1920s to more than 728 million acres in 1991. Growing trees rapidly sequester CO_2, whereas in mature forests the carbon cycle is in equilibrium. **In 1995, the United States National Oceanic and Atmospheric Administration reported that according to CO_2 isotope uptake studies as much as half of the CO_2 emitted annually is being absorbed by forests in the temperate latitudes of the northern hemisphere.** Finnish scientists have documented a 30% increase in European tree growth from 1971 to 1990. They theorize that increased air pollutants, specifically airborne nitrates and carbon dioxide, have caused a fertilization effect.

No one knows with any certainty how much CO_2 is entering the air as a result of deforestation or is being sequestered by reforestation. The prevailing view of environmentalists is that deforestation might be a substantial contributor to atmospheric CO_2 over comparatively short periods of time; extensive clearing of the rain forests will undoubtedly release large amounts. Some estimates suggest deforestation contributes from 0.9 to 1.2 billion tonnes of CO_2 annually (i.e. one-fifth the amount input by fossil fuels.) On the other hand, there is now a growing understanding of the ability of the northern boreal forest to tie-up CO_2, suggesting that the above estimates may err on the high side.

The oceans of the world contain substantially more carbon than the atmosphere, the biota and fossil fuels combined. Although much remains to be determined about how the oceans and the atmosphere exchange carbon dioxide, current research suggests that the oceans are absorbing about 40%, or 2 billion tonnes annually, of the carbon being added to the atmosphere by fossil fuel combustion.

The amount of CO_2 that can be taken up by saltwater depends upon the chemical nature of the water's dissolved materials, its temperature, and to an extent upon the effectiveness of ocean mixing. Gases such as carbon dioxide are preferentially soluble in cold water. The ocean thermocline sets up a solubility gradient that transfers carbon dioxide from the warm surface water to the cold ocean depths. Storage of carbon dioxide is further facilitated by the high pressure at deep ocean levels. The storage capacity of the ocean floor for carbon dioxide is not yet known; however, this question has stimulated considerable research interest. Already scientists in Europe and Japan are proposing the capture, transfer and storage of industrial carbon dioxide emissions at great ocean depths.

Attention has focused on the role of the world's river systems in the transfer of carbon from land to sea. In a major international study, more than 50 scientists around the globe are monitoring at least 50% of the freshwater discharge to the oceans. Preliminary results suggest that riverine systems may be a significant sink for carbon, especially in cases where dams have been constructed, impounding the sediment load in reservoirs.

The third important CO_2 sink is in the form of waste. Waste that is not naturally or manually recycled usually ends up in landfills, which today are constructed within impermeable barriers such as clay. When the landfill is full, the waste is entombed under a clay blanket which deflects rain water away from the waste. This segregation of waste from water is done to protect groundwater supplies from potentially toxic leachate; however, this action also greatly retards the rate of natural degradation. Preliminary calculations indicate that 1.0 billion tonnes of carbon a year are being segregated in this way; thus the carbon balance and global warming models should be modified accordingly.

D. Evidence of an Increase in Greenhouse Gases

1. Carbon Dioxide

Although the predicted after-effects of atmospheric carbon dioxide accumulation may be controversial, the recently measured data are irrefutable. A number of scientific observers have concluded that over the period 1850 to 1992 the atmospheric concentration of carbon dioxide

increased from perhaps 290 to 356 parts per million (ppm). More accurate measurements have shown that the concentration has risen 12 ± 1 ppm in the decade from 1970 to 1980 and had continued to rise until 1991 at approximately 1.0-1.5 ppm annually. In 1991, research scientists at the Scripps Institution of Oceanography observed that the decades-long rise in carbon dioxide had slowed abruptly to a modest 0.6 ppm per annum, while at the same time oxygen levels had increased. This reduced rate of increase may be linked to increased carbon dioxide sinks in the terrestrial biosphere and/or oceans, particularly in the northern hemisphere. Carbon isotopes studies indicate that, in the 12 months since May 1991, oceans took up an extra 0.7 gigatonnes of carbon, and terrestrial vegetation an extra 1.8 gigatonnes.

A degree of caution must be exercised when evaluating carbon dioxide data. Unlike nitrogen, which comprises about 78%, and oxygen, which comprises 21%, of total atmospheric gases, carbon dioxide now accounts for approximately 0.035%. Accordingly, a small increment in carbon dioxide concentration appears as a huge percentage increase. For example, in the 1850 to 1992 time period, the concentration of carbon dioxide as a percentage of total atmospheric gases increased from 0.029% to 0.0356%. This increment of 0.0066% as an atmospheric constituent can also be expressed as a 22.7% increase in carbon dioxide concentration. The latter expression has shock value, but scientifically is not very meaningful. What must be accurately quantitated is the correlation between atmospheric heat retention and the proportional increase of greenhouse gases in relation to total atmospheric gases.

2. Trace Gases

Methane (CH_4) is at present the trace gas that, molecule for molecule, has the greatest greenhouse effect. The sources of methane (the major component of natural gas) in the atmosphere are somewhat obscure although a recent examination lists rice paddies, biomass burning, swamps, natural gas and coal mining losses, and ruminating animals as the major CH_4 sources. Contrary to media reports, domestic cattle are probably responsible for only a small increase in methane levels. One hundred years ago North America supported 65 million bison, replaced today by 95 million cattle.

The atmosphere now contains five billion tonnes of CH_4, resulting in a concentration of approximately 1.6 ppm. Ice core dating indicates that the level of atmospheric CH_4, after being relatively constant for thousands of years, more than doubled during the past 200 years. The rate of CH_4 increase, however, has been gradually slowing down over the past decade. In 1992, scientists at the Climate Monitoring and Diagnostics laboratory in Boulder, Colorado, documented that the rate of increase had dropped very sharply in the southern hemisphere and plummeted to zero in the northern hemisphere. The reason for this dramatic reduction in the rate of CH_4 increase is not precisely known; however, a 1994 study indicates that it may be linked to stratospheric ozone depletion. Ozone breakdown in the presence of water vapour results in the production of free hydroxyl radicals (OH), which in turn are capable of oxidative reactions with other atmospheric chemicals such as CH_4. CH_4 has an atmospheric life time of only five to ten years. Given the prediction by atmospheric scientists that ozone depletion will continue for the next century, it is thus possible that atmospheric CH_4 concentrations could either stabilize or actually fall below historic levels.

The contribution of nitrous oxide (N_2O) to the greenhouse effect is approximately one-sixth that of CH_4. Unlike CH_4, which is present in the atmosphere at ppm concentrations, N_2O is present only at parts per billion (ppb). As of 1992, the atmospheric N_2O level was 310 ppb. In 1992, the rate of increase was 0.16%, which was similar to the annual growth rates measured between 1977 and 1985, but nearly half the rate (0.3%) observed between 1985 and 1991. The reason for this dramatic slow-down in growth rate is not known. Soils appear to be an important but highly variable source of N_2O. It has been noted that matching fertilizers with soil moisture conditions can inhibit nitrification and reduce emissions by up to 50%. In addition, the increased use of ammonium sulphate fertilizers, which generate the lowest emissions, should help in the stabilization of atmospheric N_2O levels. Studies in Central America show that high N_2O emissions occur during the first decade following conversion of forests to pasture land, but that emissions decline thereafter to levels below those in the original forest ecosystem. A 1994 Environment Canada review of climate research notes that past estimates for sustained large emissions from forest to pasture conversions appear to have been exaggerated.

Halons and chlorofluorocarbons (CFCs) were once thought to be powerful greenhouse gases. In February 1992, however, the IPCC reported that halons and CFCs were no longer believed to be significant contributors to global warming. According to the IPCC, the global-warming effect of CFCs is approximately balanced by CFC destruction of another greenhouse gas, ozone.

The CFC story once again changed with the November 1994 publication of a Cambridge University study that revealed how CFCs could significantly contribute to global cooling. Not only do CFCs destroy the greenhouse gas ozone, but free radicals (OH) are produced in that process. These can oxidize the greenhouse gas methane; and, even more important, promote the conversion of SO_2 to sulphuric acid, which then forms cloud condensation nuclei (CCN). Clouds formed from CCN have a denser arrangement of small droplets characterized by increased reflectivity. A decrease in mean droplet size associated with an increase in cloud-droplet concentration inhibits precipitation development. Thus, not only do these clouds reflect more sunlight away from earth, but they have a significantly longer lifetime than normal rain clouds. It should be noted that CCN particles, prior to droplet formation, can also directly reflect incoming sunlight.

In less than three years, the changing scientific knowledge about the effect of CFCs on climate change has caused a swing away from the theory that they are the most powerful greenhouse gases known and led to the realization that CFCs actually cause significant global cooling. This radical shift in knowledge indicates that climate change is a science in its infancy and underlines the enormous challenge confronting decision makers charged with the task of developing effective climate change policy.

E. Greenland Ice-Core Data

Danish scientists, studying 25,000 years of Greenland glacier ice-core data, have shown that the last glaciation ended 11,500 years ago and that the "temperature in Greenland rose about 7°C in only about 50 years." In addition, ice-core analyses have shown climate shifts from cold to warm to cold again on 11 separate occasions; each shift began abruptly, perhaps over a few

decades, but ended gradually. The Danish scientists suggest that the climatic changes in Greenland were driven by the effect of the North Atlantic current on sea ice. If this was so, the temperature fluctuation in Greenland would have been associated with significant climatic changes in the entire North Atlantic region, particularly in Europe. This correlates with the evidence provided by fossil plants.

Gas analyses of the ice cores revealed that climate warming was associated with higher CO_2 concentrations; however, increased CO_2 levels followed warming and did not precede it. Accordingly, higher CO_2 concentrations would seem to be a consequence of warming rather than the cause. Of even greater significance is the fact that, during these warm periods, high levels of CO_2 were never able to prevent the next cycle of global cooling. It therefore appears that CO_2 alone is incapable of causing irreversible warming.

Reaction to the ice-core data has been polarized. Some environmentalists claim that the data augment their fears that human releases of greenhouse gases will exceed a natural balance and trigger a period of rapid and devastating warming. In contrast, others believe that the data show that periods of warming and cooling occur naturally, that human action did not cause past warmings, and that it is very unlikely that future human action will either cause or forestall natural shifts in climate.

F. Implications of Increased Atmospheric Levels of Greenhouse Gases

Basing their work on the early assumption that a doubling of the atmospheric carbon dioxide concentration would raise the global mean temperature by as much as 4.5°C, climatologists began to develop models to predict possible climate change. According to some models, the polar ice caps would melt, flooding coastal cities and island nations. As well, rainfall patterns would change, deluging coastal regions and eroding soils, and dry grassland regions would become unproductive deserts. Further extrapolations predicted mass famine, disease and the unprecedented migration of eco-refugees. These early model predictions have already proved to be flawed. The magnitude of predicted catastrophe is being downgraded as more accurate information on cloud formation, ocean effects, plant-growth stimulation, sulphate pollution, etc. are accumulated and

applied to models. The predicted effect of global warming on sea level rise is perhaps the most startling example of forecast modification. Only a few years ago, some modellers projected a 1-metre rise in sea levels. Today, the IPCC estimates a rise of only 3 to 11 inches. Further, recent scientific articles have suggested that sea levels would actually drop. Quite simply, the climate of polar regions would become less severe and more humid, resulting in heavier snows that would augment the polar ice caps, rather than melting them.

Accurate predictions of global warming and climate change are as yet impossible to make. The atmospheric concentrations of CO_2 and N_20, are increasing, and these gases have an insulative capacity. Beyond these irrefutable facts, all other parameters, such as the global capacity to buffer the effects of these gases, are not accurately known. Weather records have been maintained only during this century, and it cannot be conclusively stated whether recent weather trends are part of normal meterological variation, or the gentle beginning of global warming. This doubt, however, is not a reason for doing nothing. Efforts directed toward the reduction of all greenhouse gases will yield substantial benefits in the areas of pollution abatement, energy conservation, efficiency, and increased competitiveness. Unfortunately, noble as these goals are, in the long term they will be only band-aid remedies, for they do not address the real causes of environmental deterioration, which are poverty, unchecked population growth, and an economic system whose health depends upon sustained growth.

PARLIAMENTARY ACTION

In October 1989, the House of Commons Standing Committee on Environment began examining policies for ameliorating global warming, including developing actions and strategies to reduce Canada's net release of greenhouse gases into the atmosphere. On 25 March 1991, the Committee tabled its report, *Out of Balance: The Risks of Irreversible Climate Change*, to Parliament. The Report contains 25 recommendations and calls for significantly increased Canadian initiatives to reduce domestic greenhouse-gas emissions, particularly carbon dioxide.

Canada is combatting possible global warming through a 3.25 million tree afforestation program (Forestry Canada), and through an Agriculture Canada program to increase

the organic content of soils. The objectives of the latter program are two-fold, to increase soil fertility and to sequester and store carbon dioxide. In addition, Bill C-41, an Act respecting the energy efficiency of energy-using products and the use of alternative energy sources, received Royal Assent on 23 June 1992. On 4 December 1992, Canada ratified the *United Nations Framework Convention on Climate Change*.

In February 1995, Canadian federal and provincial environment and energy Ministers approved Canada's National Action Program on Climate Change. Under this program the federal government and provinces will work together toward the national objective of stabilizing greenhouse gas emissions at 1990 levels by the year 2000, and pursue opportunities to further reduce emissions beyond that date. In addition, the participants are involved in the development of climate change indicators and benchmarks that will show governments how well they are doing and provide direction for future actions.

CHRONOLOGY

1958 - Dr. Charles Keeling began monitoring the concentration of carbon dioxide in the atmosphere at a station on Mauna Loa in Hawaii. The atmospheric concentration of CO_2 rose from 1958 until it abruptly slowed in July 1991. It started to resume its climb in 1993.

October 1983 - The U.S. Environmental Protection Agency released a report warning that the climatic effects of atmospheric CO_2 accumulation would become apparent in the 1990s. The U.S. National Academy of Sciences issued a report on climatic change which foresaw a somewhat similar climatic alteration in the long term but viewed the situation with less apprehension.

25 September 1984 - An Ottawa symposium on "Global Change," sponsored by the International Council of Scientific Unions, discussed a proposal to establish an International Geosphere-Biosphere Program "to assess trends in natural and anthropogenic global change anticipated for the next 50-100 years."

27-30 June 1988 - The "World Conference on the Changing Atmosphere: Implications for Global Change" (Toronto, Canada) brought together scientists and policy-makers from 46 countries as a first step towards an international convention for the protection of the atmosphere.

20-22 February 1989 - Protection of the Atmosphere: International Meeting of Legal and Policy Experts, Ottawa, Canada. This meeting examined legal and institutional considerations in the development of a global convention.

November 1990 - The World Climate Conference in Geneva, attended by some 130 countries, failed to agree on a strategy to prevent global warming. The final conference statement said that "we urge all developed countries to establish targets and/or feasible national programmes or strategies which will have significant effects on limiting emissions of greenhouse gases not controlled by the Montreal Protocol." It was suggested that the final statement was designed to keep the United States involved in negotiations, scheduled to commence in Washington in February 1991, for an international convention on climate change.

December 1990 - Environment Canada confirmed Canada's commitment, made at the World Climate Conference, to "stabilize national emissions of ... CO_2 and other greenhouse gases at 1990 levels by the year 2000."

1992 - Atmospheric methane concentrations appeared to approach stabilization at approximately 1.6 ppm, and the rate of increase in atmospheric N_2O accumulation slowed.

February 1992 - The IPCC stated that the global-warming effect of CFCs is approximately balanced by CFC destruction of another greenhouse gas, ozone.

June 1992 - Of the 161 countries participating at the United Nations Conference on Environment and Development, 154 nations signed the *United Nations Framework Convention on Climate Change*. The objective of the Convention is "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system." The Convention will enter into force 10 days after ratification by 50 State parties.

4 December 1992 - Canada ratified the *United Nations Framework Convention on Climate Change.*

November 1994 - A University of Cambridge study documented that CFCs, through their destruction of ozone and release of OH radicals, cause the oxidization of methane and the formation of highly reflective clouds around sulphate condensation nuclei. CFCs are now recognized as potent global cooling agents.

April 1995 - The Berlin Conference was held to investigate the possibility of obtaining international agreement for strengthening the wording of the *United Nations Framework Convention on Climate Change.* Countries of the European Union proposed amendments to the Convention that would have introduced a specific timetable and target for reductions of carbon dioxide emissions. Prior to the conference, an American climate change study conducted at Harvard University had concluded that there is a growing body of scientific evidence showing global warming not to be a serious threat. As of April 1995, only computer simulations of future climate scenarios have indicated that increased levels of carbon dioxide will lead to global warming. The United States, Canada, Australia and New Zealand opposed amendments to the Convention. Canada, however, remains committed to its goal of attempting to stabilize national emissions of carbon dioxide at 1990 levels by the year 2000.

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